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Changes in muscularity with growth and its relationship with other carcass traits in three terminal sire breeds of sheep

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Abstract

Data were available for 160 sheep (50 Suffolk males, 50 Suffolk females, 40 Texel males and 20 Charollais males). One-fifth of animals within each breed and sex were slaughtered at each of 14, 18 or 22 weeks of age and two-fifths slaughtered at 26 weeks. After slaughter linear measurements were taken on the carcass. The left side of each carcass was then separated into eight joints and each joint dissected into lean, bone and fat. Five muscularity measures (three for the longissimus thoracis et lumborum *(LTL) muscle, one for the hind leg and one for the whole carcass) and one of the shape of the LTL cross-section (depth : width) were calculated. With the exception of one measure for the LTL, muscularity increased with growth. Rates of increase in most measures were higher in Texels than in each of the other breeds, but were not different between the male and female Suffolks or between the Suffolk and Charollais lambs. Increases in most muscularity measures at a constant live weight were associated with increases in lean to bone ratio and carcass lean content. Associations with fat content were either non-significant or negative. Relationships with lean distribution were non-significant or weak. Correlations between the three measures of muscularity for the LTL were high. Correlations between the whole carcass measure and those within different regions were moderate to high in the Texels but lower in the Suffolk and Charollais breeds. The same was true for correlations between the LTL measures and hind leg muscularity. If muscularity throughout the carcass is to be described effectively, measures in more than one region may be required, particularly in the Suffolk and Charollais breeds.*

Keywords: *carcass composition, muscle weight, sheep.*

Introduction

The shape of a lamb carcass is considered important commercially, as is its weight and fatness. In abattoirs, carcass shape is evaluated subjectively as conformation and assessed using a scale such as the linear EUROP score. Shorter more blocky carcasses are considered of better shape and are given higher conformation scores. Traditionally, these carcasses were perceived to have a higher lean to bone ratio, higher proportions of lean in the high value joints and greater thickness of muscle at the same carcass weight, each attribute having commercial value (Jackson and Mansour, 1974; Kempster *et al.*, 1981; Harrington and Kempster, 1989; Purchas and Wilkin, 1995). In practice the positive associations between higher conformation and lean to bone ratio and increased muscle thickness have been shown but found to be weak. Moreover, higher conformation has been shown to have an undesirable positive association with fatness (Jackson and Mansour, 1974; Kempster *et al.*, 1981; Abdullah *et al.*, 1993; Purchas and Wilkin, 1995; Lewis *et al.*, 1996; Jones *et al.*, 1999).

Since fatness and conformation are confounded, an assessment of muscularity has been proposed as a preferable alternative for quantifying carcass shape (Kirton *et al.*, 1983; Purchas *et al.*, 1991; Purchas and Wilkin, 1995). Muscularity is a term used to describe, usually subjectively, the appearance/shape of muscles on a carcass. But, as yet, no standard objective methods for measuring the muscularity of a carcass are available.

De Boer *et al.* (1974) defined muscularity as 'the thickness of muscle relative to a skeletal dimension.' Despite this clear definition, early development of useful objective measures was slow and likely hindered by problems obtaining measures of muscle thickness in most regions of the carcass. This problem was largely overcome with the proposal of Purchas *et al.* (1991), that average muscle thickness can be approximated by $\sqrt{(Wt/L_B)}$, where Wt is the weight of a muscle or group of muscle's and L_B is the length of a closely associated bone. A dimensionless measure of muscularity was then obtained by further dividing this estimated thickness by the bone's length. This dimensionless property is important, since, by being independent of scale effects these measures of muscularity can be compared, justifiably, between animals of different sizes. The Purchas *et al.* (1991) approach has been used in all subsequent studies of muscularity.

Most subsequent studies have focused on the relationship between muscularity and conformation scores and a positive, but not strong association has been shown (Abdullah *et al.*, 1993; Purchas and Wilkin, 1995). Although of interest, the strength of associations with the conformation score should not be the main determinant of the most appropriate muscularity measures for a lamb carcass. The aim should be to develop a single or relatively few measures (to be practical), that are strongly associated with the carcass lean to bone ratio, the shape of different commercial cuts and if possible, with the distribution of carcass lean, both within and across breeds. The focus should therefore be on establishing the relationships between muscularity and these other measures and between muscularity in different parts of the carcass. Obtaining a good understanding of how muscularity throughout the carcass changes as lambs from different breeds grow would greatly aid these investigations.

Some of these questions have been addressed in previous studies but much remains unknown. Abdullah *et al.* (1998) showed that measures of muscularity in the hind leg and shoulder increased as Southdown lambs grew, but no information is available for measures in other regions of the carcass or in different breeds. Waldron *et al.* (1992) investigated the relationship between muscularity and composition, but only measures in the loin were used and their relationships with lean distribution were not investigated. No previous study has investigated the relationship between measures based in different parts of the carcass.

This study had three main objectives: (i) to investigate how different muscularity measures change in different breeds and sexes as lambs grow; (ii) to describe the relationships between muscularity and carcass composition and lean distribution; and (iii) to determine the relationships between muscularity measures located in different parts of the carcass.

Material and methods

Data were collected in 1997 at the Scottish Agricultural College (SAC) on 50 Suffolk male and 50 Suffolk female lambs, 40 male Texel lambs and 20 male Charollais lambs. Suffolk lambs were obtained from the SAC Suffolk flock and consisted of equal numbers within sex from the lean growth selection and control lines. Further details of the SAC Suffolk flock are given by Lewis *et al.* (1996) and Simm *et al.* (2002). Texel lambs were obtained from the ANTUR flock at the Institute of Rural Studies (IRS), Aberystwyth and consisted of equal numbers from the lean growth and leg conformation selection lines. Further details of the ANTUR flock are given by Wolf *et al.* (2001). Charollais lambs were obtained from two commercial pedigree flocks. The Suffolk, Texel and Charollais lambs were the progeny of 14, eight and eight sires respectively.

Management

Suffolk lambs were weaned at approximately 8 weeks of age. From 1 to 2 weeks prior to weaning they were offered free access to a performance test diet (12·4 MJ metabolizable energy and 178 g crude protein per kg dry matter). Texel and Charollais lambs were purchased at approximately 8 weeks of age. These lambs were gradually introduced to this same diet while providing *ad libitum* access to hay during an adjustment period. All lambs were group penned according to breed and sex, with *ad libitum* access to the diet for at least 6 weeks prior to slaughter.

Slaughter measurements

One fifth of lambs within each genotype were slaughtered at each of 14, 18, and 22 weeks of age. The remaining two fifths were slaughtered at 26 weeks of age. All lambs were assigned at random within sire families to a slaughter age. Live weights prior to slaughter were recorded. After slaughter carcasses were chilled for 24 h and then weighed. The carcass was then split and side length was measured as the distance from the cranial end of the symphysis pubis to the cranial dorsal edge of the first thoracic vertebra. The left side of the carcass was subsequently frozen and retained for dissection.

After thawing the width (A) and depth (B) of the *longissimus thoracis et lumborum* (LTL) muscle were measured on the caudal surface when the side was

Table 1 *Abbreviations and calculations used to derive the different measures for the carcass side*

Trait	Abbreviation	Calculations†
Composition		
Tissue content	Lean, fat	weight of tissue (g)/side weight (kg)
Lean to bone ratio	L : B	weight of lean/weight of bone
Lean distribution	Leg, loin, best end, shoulder	weight of lean in the joint (g)/total weight of lean in the side (kg)
Mean muscle thickness		
LTL†	AB_th	$\sqrt{(A \times B \times 0{\cdot}8)}$
Three dissected leg muscles	3M_th	$\sqrt{3M/FL}$
Total carcass muscle	TM_th	$\sqrt{TM/SL}$
Muscularity		
LTL	ASL	$(A/SL) \times 10$
	BSL	$(B/SL) \times 10$
	ABSL	$((\sqrt{A \times B \times 0{\cdot}8})/SL) \times 10$
Hind leg	3MFL	$(\sqrt{3M/FL^3}) \times 10$
Whole side	TMSL	$(\sqrt{TM/SL^3}) \times 1000$
Shape		
LTL cross section	B : A	$(B/A) \times 10$

† A and B are the width and depth of the *longissimus thoracis et lumborum* (LTL) muscle respectively (mm); SL, FL are the length (cm) of the carcass side and femur respectively; 3M is the combined weight of the *semitendinosus*, *semimembranosus and gluteobiceps* muscles dissected from the hind leg (g); TM is the total weight of lean in the left side of the carcass (kg).

cut between the last and second to last thoracic vertebrae (Palsson, 1939). The area of the LTL surface was not directly measured but approximated by $A \times B \times 0{\cdot}8$ as done by Hopkins *et al.* (1993).

The left side of the carcass was separated into the eight joints as described by Cuthbertson *et al.* (1972). Each joint was weighed and then dissected into lean, bone, fat (subcutaneous and inter-muscular) and waste. Three muscles from the hind leg (*semitendinosus*, *semimembranosus* and *gluteobiceps*) were individually separated and their weights recorded. Length of the femur was measured. Further details of measurements recorded are given in Table 1.

Muscularity and LTL cross-section shape measures

Three measures of muscularity for the LTL were derived based on cross-sectional dimensions of the LTL muscle and side length. These were the ratio of LTL width (A) to side length (ASL), the ratio of LTL depth (B) to side length (BSL) and the ratio of 'average thickness' of the muscle at the point of measurement (square root of its area) to side length (ABSL). A measure of muscularity in the hind leg and one for the whole carcass were derived using the approach of Purchas *et al.* (1991). The hind leg measure was based on the length of the femur and the combined weight of the three dissected muscles (3MFL), and the whole carcass measure was derived using the total weight of lean in the side and side length (TMSL).

A measure of the shape of the LTL cross-section was defined as the ratio of muscle depth to width (B : A). Details of each of the muscularity and B : A measures are given in Table 1.

Statistical analysis

Data for two Suffolk males and three Suffolk females were removed. Their live weights were greater than two standard deviations below the mean for their respective slaughter age groups (within breed-sex) causing the distribution to be highly skewed ($P < 0{\cdot}05$).

The distribution of live weight across slaughter age groups was continuous in each breed-sex with considerable overlap between contiguous age groups. This allowed a linear regression on live weight to be fitted across age groups. Within each breed-sex, for each muscularity measure, once a linear regression on live weight was fitted, age group and a quadratic regression on live weight did not explain additional variation ($P > 0{\cdot}05$). The same was true for each composition and lean distribution measure considered. The effect of age group and a quadratic regression on live weight were therefore not included in any of the subsequent models fitted.

Regression on live weight

Values for each of the muscularity and B : A measures were regressed individually on live weight within each breed-sex to investigate how these measures change with growth. Prior to analysis each lamb's live weight was expressed as a deviation from the mean live weight for the 14 week slaughter group in their respective breed-sex. The intercept for the regression on adjusted live weight within each breed-sex was then used to assess whether breeds and sexes differed in their muscularity values at the start of the study. Mean weights for the 14 week slaughter groups were 41·7, 36·7, 38·1 and 30·0 kg for the Suffolk males, Suffolk females, Charollais and Texels, respectively.

In order to facilitate comparisons between breed-sexes, all data were combined and breed-sex fitted as an effect in the model. In preliminary investigations, slopes for the regression of each muscularity and B : A measure on live weight did not differ between the Suffolk males, Suffolk females and Charollais males, but were frequently different from that estimated for the Texel males ($P < 0{\cdot}05$). A single common slope was therefore fitted for data from the Suffolk males, Suffolk females and Charollais lambs in the analysis, whilst a separate slope was fitted for the Texel lambs.

Allometry

Changes in muscularity with growth occur as a consequence of differences in the relative growth rate of the measure's components. These relative growth rates can be investigated in more detail using allometry (Huxley, 1932). Allometric coefficients (β) were derived from the slope of a log/log regression of each muscle thickness (included in the measures) on its associated skeletal dimension.

Relationship with composition and lean distribution

Relationships between the muscularity measures and carcass composition and lean distribution after accounting for the effect of live weight were investigated using multiple regression (Genstat, 1994). The models fitted included the effect of breed-sex, live weight and one of the muscularity or B : A measures as linear co-variates. The interaction between breed-sex and both co-variates was also fitted in preliminary analyses, however, slopes for the regression on live weight were not different ($P > 0{\cdot}05$) between the Suffolk males and females and the Charollais and therefore a single common slope was fitted for these breed-sexes. This was also true for the regression on the muscularity and B : A measures and therefore a common slope was also fitted for this regression for the Suffolk and Charollais lambs.

Correlations between the muscularity and B : A measures

Correlations between residuals (from the regression of each measure on live weight), for each of the five muscularity measures and LTL shape were estimated within each breed-sex separately (Genstat, 1994). These estimates were then compared by transforming them to z values using the Fisher transformation and testing the difference between these values (Zar, 1996). Comparisons were conducted initially across all four estimates using a multiple sample test (experiment wise error rate of 5%), and subsequently between pairs where differences had been detected (comparison wise error rate of 5%).

Correlation estimates for the Suffolk male, Suffolk female and Charollais lambs did not differ ($P > 0{\cdot}05$). A common correlation coefficient was therefore calculated for these breed-sexes. The common coefficient was subsequently compared with that estimated for the Texels.

Results

Muscularity measures were consistently higher in the selection than in the control line in both Suffolk sexes. Hind leg muscularity was also higher in the leg conformation line than in the lean growth line in the Texels (results not shown). However, differences

Table 2 *Intercepts (α) for each breed-sex from the regression of the muscularity and B : A measures on live weight (adjusted)†*

	Suffolk males α (s.e.)	Suffolk females α (s.e.)	Charollais males α (s.e.)	Texel males α (s.e.)
Muscularity				
ASL	10·648 (0·152)[a]	10·547 (0·136)[a]	10·772 (0·182)[a]	11·943 (0·195)[b]
BSL	5·871 (0·130)[ac]	5·520 (0·116)[b]	5·613 (0·155)[ab]	6·205 (0·166)[c]
ABSL	7·064 (0·116)[a]	6·822 (0·104)[b]	6·953 (0·139)[ab]	7·689 (0·149)[c]
3MFL	3·994 (0·052)[a]	3·971 (0·046)[a]	3·771 (0·062)[b]	4·161 (0·066)[c]
TMSL	5·101 (0·050)[a]	4·945 (0·045)[b]	5·271 (0·060)[c]	5·981 (0·064)[d]
Shape				
B : A	5·513 (0·092)[a]	5·253 (0·082)[b]	5·205 (0·111)[b]	5·167 (0·118)[b]

[a,b,c] Within rows, intercepts with different superscripts differ ($P < 0{\cdot}05$).
† Live weights were adjusted such that intercepts represent values at the mean weight for the 14 week age group within each breed-sex, which were 41·7, 36·7, 38·1 and 30·0 kg for the Suffolk males, Suffolk females, Charollais and Texels, respectively.

Table 3 *Coefficients (β) for Suffolks/Charollais and Texels for the regression on live weight and residual standard deviations and coefficients of variation (CV) for each of the muscularity and B : A measures*

	Suff/Char β (s.e.) †	Texels β (s.e.)	diff‡	Residual s.d.§	CV§
Muscularity					
ASL	–0·018 (0·005)***	0·001 (0·010)		0·70	0·064
BSL	0·002 (0·004)	0·040 (0·009)***	***	0·58	0·094
ABSL	–0·005 (0·004)	0·025 (0·008)**	***	0·52	0·071
3MFL	0·007 (0·002)***	0·013 (0·004)***		0·24	0·056
TMSL	0·003 (0·002)	0·012 (0·003)***	*	0·23	0·040
Shape					
B : A	0·011 (0·003)***	0·035 (0·006)***	***	0·43	0·077

† Superscripts indicate the significance of differences from zero.
‡ Significance of the difference between the two coefficients.
§ Pooled within breeds-sex estimates. CV calculated using the residual standard deviation.

were small relative to the standard errors for line means ($P > 0{\cdot}05$). The effect of selection line was therefore ignored in subsequent analyses.

Regression on live weight

Intercepts for the regression of the muscularity measures on adjusted live weight for each breed-sex are shown in Table 2. The intercept for each of the muscularity measures was higher for the Texel than for any of the other breed-sexes suggesting that greater development in muscularity had occurred in this breed by 14 weeks of age. Differences at this age between the Suffolk and Charollais lambs were less pronounced.

The coefficients for the regression on live weight represent the rate of development in muscularity between 14 and 26 weeks of age. These coefficients, pooled residual standard deviations and coefficients of variation (CV) (calculated using the residual s.d.), are shown for each of the muscularity and B : A measures in Table 3. Increases in live weight were associated with increases in the B : A measure and a number of the muscularity measures. A significant negative coefficient was estimated only for the ASL in the Suffolk's and Charollais (Suff/Char). Coefficients tended to be higher in the Texels, particularly for BSL and ABSL where the difference between the Texels and Suff/Char was most pronounced ($P < 0{\cdot}001$).

Table 4 *Allometric coefficients (β) for Suffolks/Charollais and Texels derived from the double logarithmic regressions of muscle thicknesses on their associated skeletal lengths or muscle width*

X	Y	Suff/Char β (s.e.)	Texels β (s.e.)	diff †
SL	A	0·635 (0·087)‡	1·050 (0·117)	**
SL	B	0·947 (0·134)	1·773 (0·182)‡	***
SL	AB_th	0·791 (0·100)‡	1·411 (0·135)‡	***
FL	3M_th	1·163 (0·098)	1·205 (0·115)‡	
SL	TM_th	1·034 (0·058)	1·157 (0·079)‡	
A	B	1·059 (0·101)	1·525 (0·117)‡	**

† Significance of the difference between the two allometric coefficients.
‡ Different from 1 ($P < 0{\cdot}05$).

Allometry

The allometric coefficients reflect differences in relative growth between muscle thickness and its associated skeletal dimension (Table 4). Muscle thickness increased at a greater rate than its associated bone length ($\beta > 1{\cdot}0$), except for measures of LTL thickness for the Suff/Char. Coefficients were generally higher for the Texels than for the Suff/Char. The differences were again most pronounced for measures based on the LTL ($P < 0{\cdot}01$).

Relationship with composition and lean distribution

Intercepts and coefficients for the regression of each composition and lean distribution variable on adjusted live weight are shown in **Appendix 1**. Results for lean distribution are only shown for the four joints where the additional regression on one or more of the muscularity measures was significant. Comparison between breed-sexes of how these variables change with live weight is not the focus of this study and therefore will not be considered in any detail.

Partial coefficients for the regression of composition and lean distribution on each of the muscularity and B : A measures, when fitted individually with live weight are shown in Table 5 and 6.

Table 5 *Partial coefficients (s.e.) for LTL muscularity measures, derived from the multiple regression of each composition or lean distribution variable on live weight and the muscularity measure for Suffolks/Charollais and Texels*

	ASL			BSL			ABSL		
	Suff/Char †	Texels	diff‡	Suff/Char	Texels	diff	Suff/Char	Texels	diff
Composition									
Lean (g/kg)	21·620 (3·627)***	19·169 (5·236)***		17·153 (4·877)***	10·958 (6·258)		26·059 (5·160)***	17·802 (6·659)**	
Fat (g/kg)	–26·349 (4·367)***	–11·793 (6·303)		–17·945 (5·836)**	–4·715 (7·494)		–29·557 (6·221)***	–9·363 (8·034)	*
L : B	0·041 (0·043)	0·252 (0·063)***	**	0·099 (0·054)	0·202 (0·069)**		0·098 (0·059)	0·279 (0·076)***	
Lean distribution									
Leg (g/kg)	–0·745 (1·431)	0·146 (2·065)		0·515 (1·745)	2·271 (2·243)		–0·053 (1·946)	1·815 (2·514)	
Loin (g/kg)	0·335 (0·985)	2·534 (1·422)		0·949 (1·215)	0·756 (1·554)		0·954 (1·349)	1·856 (1·734)	
Best end (g/kg)	1·773 (0·439)***	3·251 (0·633)***		1·832 (0·556)***	3·092 (0·711)***		2·426 (0·598)***	3·928 (0·768)***	
Shoulder (g/kg)	–0·420 (1·120)	–4·760 (1·617)**	*	–0·851 (1·373)	–4·892 (1·765)**		–0·882 (1·520)	–6·061 (1·962)**	*

† Superscripts indicate the significance of differences from zero.
‡ Significance of the difference between the two coefficients.

Table 6 *Partial coefficients (s.e.) for the 3MFL, TMSL and B : A measures, derived from the multiple regression of each composition or lean distribution variable on live weight and the muscularity or B : A measure for Suffolks/Charollais and Texels*

	3MFL			TMSL			B : A		
	Suff/Char †	Texels	diff ‡	Suff/Char	Texels	diff	Suff/Char	Texels	diff
Composition									
Lean (g/kg)	54·274 (13·181)***	3·003 (13·466)		86·120 (13·500)***	31·719 (12·228)*	**	–2·766 (6·552)	–3·771 (11·041)	
Fat (g/kg)	–39·814 (16·204)*	11·703 (16·553)	*	–82·062 (16·955)***	5·480 (15·360)	***	7·684 (7·650)	8·392 (12·890)	
L : B	0·637 (0·113)***	1·126 (0·115)***	**	0·632 (0·132)***	1·015 (0·120)***	*	0·091 (0·071)	0·104 (0·120)	
Lean distribution									
Leg (g/kg)	13·386 (4·615)**	8·100 (4·715)		–1·288 (5·300)	3·473 (4·799)		2·176 (2·204)	4·691 (3·714)	
Loin (g/kg)	9·534 (3·206)**	6·036 (3·275)		0·457 (3·683)	2·990 (3·336)		1·187 (1·543)	–1·829 (2·600)	
Best end (g/kg)	0·565 (1·627)	4·490 (1·662)**		2·303 (1·821)	2·866 (1·650)		0·561 (0·762)	2·591 (1·285)*	
Shoulder (g/kg)	–12·998 (3·540)***	–13·941 (3·617)***		–6·096 (4·065)	–13·386 (3·683)***		–0·938 (1·779)	–4·591 (2·997)	

† Superscripts indicate the significance of differences from zero.
‡ Significance of the difference between the two coefficients.

Table 7 *Residual correlations (from regressions on live weight) between the muscularity and B : A measures for Suffolks/Charollais (pooled estimates) and Texels*

(a) Suffolks/Charollais Indices		ASL	BSL	ABSL	3MFL	TMSL	B : A
Muscularity							
LTL	ASL	—					
	BSL	0·56	—				
	ABSL	0·84	0·93	—			
Hind leg	3MFL	0·14†	0·19†	0·20†	—		
Whole side	TMSL	0·53	0·52	0·59	0·38†	—	
Shape: LTL	B : A	–0·15	0·74	0·43	0·11	0·19	—

(b) Texels Indices		ASL	BSL	ABSL	3MFL	TMSL	B : A
Muscularity							
LTL	ASL	—					
	BSL	0·71	—				
	ABSL	0·89	0·96	——			
Hind leg	3MFL	0·52†	0·56†	0·60†	—		
Whole side	TMSL	0·56	0·61	0·64	0·74†	—	
Shape: LTL	B : A	0·16	0·81	0·60	0·38	0·40	—

In (a) correlations less than 0·18 do not differ from zero ($P > 0{\cdot}05$).
In (b) correlations less than 0·27 do not differ from zero ($P > 0{\cdot}05$).
† Correlations are significantly different between the two groups ($P < 0{\cdot}05$).

All five of the muscularity measures were positively associated with increased lean content and negatively associated with carcass fat content in the Suff/Char. The positive association with leanness was also present for most of the muscularity measures in Texels. Muscularity was not associated with fatness in the Texels ($P > 0{\cdot}05$). Increases in each muscularity measure were associated with increases in the carcass lean to bone ratio in Texels. However, this was only so for 3MFL and TMSL in the Suff/Char. The regression on B : A was not significant for any of the composition measures.

The relationship between the muscularity measures and proportion of lean in the high priced joints (leg and loin) was weak. A significant relationship was only present with 3MFL in the Suff/Char, where an increase in 3MFL was associated with a higher proportion of total lean in both joints. Differences in muscularity however, were associated with the proportion of lean found in the best end and shoulder joints. Higher LTL muscularity was associated with an increase in the proportion of lean found in the best end joint in each breed, as was a higher value for 3MFL in the Texels. Increases in each muscularity measure was also associated with a reduction in the proportion of total lean in the shoulder for Texels, but this association was only important for 3MFL in the Suff/Char. Even where these associations were significant, the amount of total variation in lean proportion in any joint accounted for by both the regression on live weight and the muscularity measure was low (< 50%).

Correlations between the muscularity and B : A measures

Correlation between residuals (from the regression of each measure on live weight), for each muscularity and shape measure, estimated for the Texels, and the common coefficient calculated for the Suffolk and Charollais are shown in Table 7.

Correlations between the ASL and BSL were high (0·56 to 0·71). As expected correlations between both these and ABSL were also high (>0·84). All correlation estimates were higher in the Texels than in the Suff/Char, with the differences often being significant. This was the case for correlations between hind leg muscularity and each of the LTL muscularity measures where estimates for Suff/Char were consistently low (<0·21) whereas those for Texels were high (>0·52). The same was also true for estimates between hind leg muscularity and the whole carcass measure (TMSL). With the exception of BSL and ABSL, correlations between the measures of muscularity and the LTL shape were comparatively low.

Discussion

Regression on live weight and allometry

The results presented here agreed with those of Abdullah *et al.* (1998) for Southdown in that for each breed-sex, hind leg muscularity increased with growth. However, muscularity in other regions of the carcass did not develop in the same way across all breeds and sexes.

Differences between the Texels and both Suffolk and Charollais lambs in the developments of muscularity with growth were clearly observed. Despite being lighter, Texel lambs had higher values for each of the muscularity measures at 14 weeks of age. The subsequent rate of development also tended to be higher for each measure, particularly for LTL muscularity. In addition to these results, partial correlations between the different measures in the subsequent analysis were also consistently higher for the Texels, implying that they differed in the way muscularity developed throughout the carcass, tending to be more uniform than in the other breeds.

Numerous studies have shown that Texels differ from other breeds in terms of composition, being leaner and with a higher lean to bone ratio when compared at either a fixed weight or fatness (Wolf *et al.*, 1980; Cameron and Drury, 1985; Kempster *et al.*, 1987; Ellis *et al.*, 1997). Although thought to be more muscular, few studies have compared muscularity in Texels with that in other breeds. Holloway *et al.* (1994) and Hopkins *et al.* (1997) considered a measure in the hind leg and found that the crossbred progeny of Texel rams at a fixed carcass weight were more muscular than those sired by rams from four other breeds. However, neither study included lambs sired by Suffolk or Charollais rams, which along with the Texel, are the most important terminal sire breeds in the UK (Maniatis and Pollott, 1998).

The greater and more uniform development of muscularity with growth in Texels coincided with lighter live weights at all ages compared with the Charollais and Suffolks. Direct comparisons of weights at an age should be made cautiously since the lambs were obtained from different sources. Nevertheless, it is worth noting that Suffolk and Charollais males were on average proportionately 0·39 and 0·27 heavier respectively than Texel males at 14 weeks and this increased to 0·49 for the Suffolks in the 26 week age group. Slower rates of growth for Texels, particularly in relation to Suffolk lambs, have also been reported in numerous other studies for purebred and crossbred lambs (Wolf *et al.*, 1980; McEwan *et al.*, 1988; Leymaster and Jenkins, 1993). Clearly, much still remains unknown about the underlying biological differences between the Texel and other breeds in terms of their development during growth.

Relationships with composition

Although dimensionless, the muscularity measures were not completely independent of live weight across breeds-sexes. So too composition changed as animals grew. Once adjustments for the effects of live weight were made, higher muscularity was associated with an increased carcass lean content and decreased fat content in the Suff/Char. The same was true of lean content in the Texels yet not for fatness.

Only one previous study has investigated the relationships between muscularity and composition. Waldron *et al.* (1992) estimated phenotypic and genetic correlations between four muscularity measures, based on the weight or dimensions of the LTL and carcass length, and lean and fat weight and lean to bone ratio in the carcass of Romney cross lambs. Phenotypic correlations with lean weight and lean to bone ratio were positive for each measure. Phenotypic correlations with fatness were small yet positive with three of the measures (<0·30), but negative with the fourth measure that incorporated the width of the LTL. The fact that Waldron *et al.* (1992) used tissue weights and fitted age as a covariate in their model does not allow good comparisons to be made with the results of this study. Nevertheless, Waldron *et al.*'s results are in general accordance with those presented here.

In contrast, Purchas *et al.* (1991) and Abdullah *et al.* (1998), reported higher muscularity at a fixed carcass weight, in Southdown lambs from lines selected for high *versus* low weight-adjusted back fat depth for five generations. This suggests a positive association exists between muscularity and fatness in the Southdown breed, but neither study quantified the strength of the relationship, which although positive, may be weak. Abdullah *et al.* (1998) stated that their results were in agreement with those reported by Simm and Murphy (1996) where crossbred progeny of Suffolk rams selected for improved lean growth had lower conformation scores at the same carcass weight than those of unselected rams. However, it is important to note that the progeny of rams from the unselected line were fatter which, given the positive correlation between fatness and conformation, would contribute towards a higher conformation score. The Suffolk lines used in the current study are the same as for the rams used by Simm and Murphy (1996). Results of our preliminary analyses refute the conclusions of Abdullah *et al.* (1998). When compared at the same live weight, differences between lines in each of the muscularity measures were non-significant, but tended to be higher in the selection line. Since purebred lambs were used in this current study, any line differences are expected to be more pronounced than for the crossbred lambs considered by Simm and Murphy (1996). Differences in conformation score should not therefore, be used as an indication of differences in muscularity, especially where carcasses vary in fatness.

Relationships with lean distribution

Relationships between muscularity and lean distribution tended to be weak. The proportion of lean found in the higher priced joints was only associated, albeit positively, with increases in the hind leg measure in the Suff/Char. Any correlated changes in joint proportions as a consequence of differences in muscularity are therefore likely to be of negligible commercial importance. Similar conclusions were drawn in previous studies investigating the effect of conformation on the distribution of lean in the carcass (Jackson and Mansour, 1974; Kempster *et al.*, 1981). The results of this study show that even when measures are used which are specifically related to the shape of individual joints and are largely independent of fatness, there remains little scope for affecting the distribution of lean in the lamb carcass through changes in shape.

Correlations between the muscularity and B : A measures

A large number of measures would be required if the relationships between muscularity in all regions of the carcass were to be investigated comprehensively. From a commercial viewpoint increased muscularity is likely most important in the high priced joints. It therefore follows that measures based in the loin and leg (such as the LTL and 3MFL measures used here), should form the main focus of investigations into potential measures of carcass muscularity. The relationship with these measures can also be used as a good basis to evaluate the usefulness of more general whole carcass measures (TMSL), or measures which can be obtained relatively simply on the cut carcass (B : A).

Correlation estimates between the three LTL muscularity measures were high suggesting that the LTL muscularity may be adequately described using any of the measures. Estimates between these measures and muscularity in the hind limb also tended to be high in the Texels (>0·51), but were low in the Suff/Char (<0·21). This implies that muscularity in one region may not always be a good indicator of the degree of muscularity in the other, across breeds. Equally, correlations between TMSL and measures in the loin and leg were high in the Texels, but less with hind leg muscularity in the Suff/Char. Whereas carcass muscularity may be adequately described using a single measure such as TMSL in Texels, this seems less appropriate for lambs from the Suffolk and Charollais breeds. Two or more separate measures may be required if characterizing the muscularity of each region is considered sufficiently important.

With the exception of BSL and ABSL, correlations between B : A and other muscularity measures tended to be low and hence the B : A measure is unlikely to be useful as a general measure of muscularity through the carcass. This may in part reflect a greater effect of measurement errors given that both dimensions in the measure are small and are taken on soft tissues. Nevertheless, the B : A measure may have some value as an indicator of BSL where a measure of side length is not available.

Live weights for animals in the present study, with the exception of animals in the lower age group, were similar to the range over which pedigree animals are evaluated as part of selection programmes in the UK. The results of the study indicate that improved muscularity is not associated with detrimental effects in composition or lean distribution at the phenotypic level, once adjustments for differences in live weight are made. This suggests that muscularity could be incorporated into selection programmes, which include reducing fatness among the objectives, without undue reductions in selection responses. However, to be incorporated effectively methods of assessing the muscularity of the live animal may be required. At present, such methods are not available and further research would be needed for these to be developed.

Selection for improved muscularity *per se* is relevant only if improvement in the shape and thickness of muscle in cuts has commercial value. As mentioned by Hopkins (1996), unless consumer purchasing decisions are significantly affected by the surface area of muscle and shape of cuts, then the development of methods for assessing muscularity would not be useful. At present a consumer preference for cuts from more muscular joints is assumed rather than known. This still requires confirmation through market research.

Conclusions

This study has clearly shown that muscularity can be assessed objectively in the carcass in a way that is largely independent of fatness. Following adjustments for live weight, increases in muscularity are associated with increases in L : B ratio, carcass lean content, and in the Suffolk and Charollais breeds, with decreases in fat content. Additionally, increased muscularity is not deleterious to the proportion of lean in the high value joints.

The challenge now is to determine genetic and phenotypic parameters among muscularity measures and other carcass traits and to assess the feasibility of incorporating such measurements into selection programmes. The latter is likely to depend on the scope for developing useful measures of muscularity on the live animal. Still, selection for increased muscularity is useful only if it increases economic returns to one or more sectors of the sheep industry. Therefore, there exists a need to accurately determine the value of muscularity *per se* to the consumer, processor and to the lamb producer.

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Appendix 1 *Intercepts (α) and coefficients (β) for each breed-sex for the regression of each composition and lean distribution variable on live weight (adjusted)†*

	Suffolk males α (s.e.)	Suffolk females α (s.e.)	Charollais males α (s.e.)	Texel males α (s.e.)	Suff/Char β (s.e.)‡	Texels β (s.e.)	diff §
Composmition							
Lean (g/kg)	588·340 (6·306)^{a}	563·552 (5·637)^{b}	610·366 (7·562)^{c}	681·121 (8·100)^{d}	−2·555 (0·204)***	−2·497 (0·435)***	
Fat (g/kg)	207·467 (7·391)^{a}	251·272 (6·606)^{b}	197·013 (8·862)^{a}	126·677 (9·493)^{c}	3·970 (0·239)***	4·176 (0·510)***	
L : B	2·999 (0·069)^{a}	3·262 (0·062)^{b}	3·368 (0·083)^{b}	3·856 (0·088)^{c}	0·011 (0·002)***	0·022 (0·005)***	
Lean distribution							
Leg (g/kg)	293·764 (2·138)^{a}	303·376 (1·911)^{b}	285·338 (2·563)^{c}	307·010 (2·746)^{b}	−0·305 (0·069)***	−1·000 (0·147)***	***
Loin (g/kg)	117·792 (1·489)^{a}	116·225 (1·331)^{a}	111·859 (1·786)^{b}	101·924 (1·913)^{c}	0·035 (0·048)	0·460 (0·103)***	***
Best end (g/kg)	60·008 (0·744)^{a}	59·346 (0·665)^{ab}	57·908 (0·893)^{b}	51·736 (0·956)^{c}	−0·076 (0·024)**	0·149 (0·051)**	***
Shoulder (g/kg)	198·659 (1·725)^{a}	196·587 (1·542)^{a}	210·255 (2·069)^{b}	208·502 (2·216)^{b}	−0·154 (0·056)**	−0·339 (0·119)**	

^{a,b,c,d} Within rows, intercepts with different superscripts differ ($P < 0·05$).
† Live weights were adjusted such that intercepts represent values at the mean weight at 14 week for each breed-sex, which were 41·7, 36·7, 38·1 and 30·0 kg for the Suffolk males, Suffolk females, Charollais males and Texel males respectively.
‡ Superscripts indicate the significance of differences from zero.
§ Significance of the difference between the two regression coefficients.